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Final Report, Executive Summary

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Water Recovery and Solid Waste Processing for Aerospace and Domestic Applications

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NASA Contract NAS9-12504

FINAL REPORT,
EXECUTIVE SUMMARY

WATER RECOVERY AND SOLID WASTE PROCESSING FOR AEROSPACE AND DOMESTIC APPLICATIONS

JANUARY, 1973

Approved by:

Ernest A. Schumacher

Ernest A. Schumacher
Program Manager

Submitted to:

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas
Urban Systems Project Office
Technical Monitor: Reuben E. Taylor

i

FOREWORD

This document describes the results of a study for the formulation of the preliminary design of a water management system. The system is suitable for closed loop recycling of wastewater to potable water for a group of (500) dwelling units. As indicated in the contract Statement of Work, a second phase of the program is to be accomplished on a following contract which will include the design, development, manufacture, and demonstration of a system which will provide data applicable to both aerospace and domestic systems.

The report is submitted to the National Aeronautics and Space Administration, Manned Spacecraft Center, Urban Systems Project Office, under Contract NAS9-12504 in accordance with Line Item 3 of the Contract Data Requirements List Number T-644.

The overall objective of the study was to select optimum unit processes which, when integrated into a total system provide for the production of potable water from a domestic wastewater source. State-of-the-Art Aerospace and Municipal Wastewater Treatment Technology were both studied for application to this task.

Tasks conducted during this program included: studies of domestic water use profiles and available domestic plumbing hardware; establishment of a baseline concept; review of aerospace technology concepts and hardware for domestic application, establishing candidate unit treatment processes; formulation of the preliminary design; development of a computer program for system performance determination, and a conceptual test program.

ACKNOWLEDGEMENTS

The leadership of NASA; under the program technical monitor, Mr. Reuben E. Taylor of the Urban Systems Program Office, was instrumental in establishing the constraints employed in this study and in providing guidance. Mr. Richard D. Heaton, Reclamation Engineer, of the Board of Water Commissioners for Denver acted in the capacity of consultant in this study.

The following individuals of the Martin Marietta Corp. have made significant contributions to this report:

Mr. D. C. Ihrig

Mr. J. V. Mayeux

Mr. C. Murawczyk

Mr. R. B. Weber

CONTENTS

ABSTRACT

The final report describes the effort accomplished under Contract NAS9-12504 in (a) compiling information needed to establish the current water supply and wastewater processing requirements for dwellings and (b) developing a preliminary design for a wastewater to potable water management system. Data generated as a result of item (a) above was used in the formulation of design criteria for the preliminary design of the wastewater to potable water recycling system. The system as defined herein was sized for a group of 500 dwelling units.

Study tasks required by the Contract Statement of Work and summarized in this report included:

Water Consumption - The domestic water use profile, peak-load, and hot water requirements are discussed for the typical dwellings. An average family occupying a typical dwelling uses water for the purposes of drinking, food preparation, dishwashing, toilet use, bathing, laundering, garbage disposal, lawn watering, household cleaning, etc. It was assumed that a household shall have sufficient amounts of hot and cold water on demand.

Nature of Domestic Water - Individual household wastewater quality is, in most respects, similar to that encountered in domestic wastewater treatment plants handling limited industrial discharges. Wastes from houses, mobile homes, and apartments are mixed within the municipal sewage system to produce relatively constant per capita amounts of suspended solids and organic matter in terms of BOD and COD.

Fresh household sewage has a slightly soapy or oily odor and in appearance is cloudy; somewhat like grey dirty dishwater. It is normally alkaline when fresh but tends to acidify as it becomes stale in 2 to 8 hours. It is well to keep in mind that wastewater is essentially 99.97% pure water and only .03% additional material.

Consumer Appliances for Low Water Consumption - After reviewing the data gathered from different manufacturers of plumbing fixtures and major appliances, it becomes quite apparent that even though the manufacturers of these devices are cognizant of water problems and waste water flow, no significant development which impacts this problem has come out since the 1968 EPA Report.* This is primarily due to lack of public interest for such devices, the added costs incurred in the Research and Development of such devices, and the lack of public awareness concerning water shortage.

*A study of Flow Reduction and Treatment of Wastewater from Households 11050 FKE, Dec. 1969.

It should be noted, however, that a reduction of daily water flow in a "recycling situation" reflects itself largely in the recycling system pumping power consumption. This is rather insignificant when weighed against the cost of special water savings devices and the problem associated with reorientation of the public.

Water Quality Monitoring - In order to achieve safe recycling of domestic wastewater for potable application, it will be necessary to provide the capability of monitoring the following parameters:

(a) Biological quality
(b) Total dissolved solids
(c) Ph
(d) Suspended material
(e) Organic content
(f) Oxygen demanding substances
(g) Inorganic ions

It is proposed that with close control of these seven areas that a sufficient number of quality parameters will be included to insure a potable water. The history of reliability data to verify a successful operation with a limited number of in-line monitors will be derived in the developmental stages of the prototype water recovery system.

Baseline Concept - The baseline concept was defined as the dwelling plumbing system which would emphasize the utilization of available low water consumption devices. It was to require little or no additional effort on the part of the user from use of conventional systems currently being installed. The baseline concept, based on the above considerations was defined as containing one and a half baths, a dishwasher, kitchen sink, disposal unit, and clothes washer. Use will be made of the water saving low profile toilet and aerator faucets. The net result of this approach is three-fold:

(a) Assured public acceptance
(b) A 12.5% water savings
(c) A system which meets existing codes

Current and Projected Costs - In order to evaluate the economic impact of advanced plumbing systems as well as that of recycling of wastewater, the study included the development of current and projected cost data for:

(a) The baseline concept
(b) Growth trends in water and sewage requirements
(c) Current and projected cost of water supply and waste water collection
(d) Current and projected cost of water distribution and sewage mains and trunks.
(e) Current and projected cost of wastewater processing
(f) Current and projected total water and sewage costs.

The six foregoing cost elements are recognized as being essential to any economic evaluation of the use of advanced plumbing systems or advanced waste treatment technology. However, future systems costs will be a function of the population, area served, land acquisition, quality of product water, construction and operating parameters - building materials, electricity, gas, etc. Therefore, each application is unique unto itself and must be evaluated on an individual basis. Cost data presented in the report are only indicative of typical examples and may be used to establish trends rather than applied in detail to specific applications. It has been clearly established that as water quality and effluent standards increase through Federal enforcement, newer and better processes will be needed to accomplish the goal. The preliminary design resulting from this study will meet that goal.

Applicable Aerospace Technology Concepts and Hardware - There have been many processes or techniques devised to accomplish the tasks of water recovery and waste management for aerospace application. However, few of these have ever reached the prototype stage and even fewer have resulted in qualified systems. It is significant to note that aerospace potability standards are much less stringent for this application than for domestic application which must meet the test of a lifetime application. Furthermore, these systems depend on control of the "input side". Such control is not possible in the domestic situation which exposes the water treatment system to a much wider range of pollutants.

Integrated System Design - In order to formulate a conceptual design of a water management system for a group of 500 dwellings utilizing the Recycling of Wastewater Concept, it is necessary to examine a large number of unit treatmemt processes for the wastewater. These processes range from "Grit Removal" at the input to the wastewater treatment plant to the final process of "Sludge Disposal". The review and integration of these unit processes led to the definition of the preliminary design of the system.

Preliminary Design - The pollutant removal from wastewater is best achieved by the use of biological processes as the first part of the treatment system. These primary and secondary processes can be implemented by the use of "packaged systems" which offer several advantages. Many of the systems available have been operating successfully for years. These units reflect the latest technology in biological sewage treatment, yielding the highest quality effluent possible. Package units are mass constructed which greatly reduce design and building costs. However, the foregoing steps represent the simplest portion of the overall treatment process and must be followed by advanced tertiary treatment processes which are not "off-the-shelf". These unit processes when integrated and and appended to the "primary/secondary" cycle will produce a potable grade water. The unit processes include: chemical precipitation,

recarbonation, filtration, nitrogen removal, carbon adsorption, reverse osmosis, and disinfection. It is the sum total of the above treatment approach that constitutes the system preliminary design.

Computer Program - The application of computer technology makes it possible to design and monitor a water treatment system for any influent flow rate and any influent contaminant level. A program entitled "MONITOR" developed under this contract predicts the removal of 52 contaminants through any or all of 11 system processes. The program shows the hourly sewage influent and system backwash rates over a 24-hour period. A surge storage tank allows continuous operation at an hourly flow equal to the total flow divided by 24. The flow rates through each system process are calculated. Finally, the user has the option to have MONITOR design each tank required. The design option gives a scaled computer drawing of each tank.

Program "MONITOR" investigates a primary, secondary and tertiary water treatment facility capable of yielding a consistent quality potable water.

Conceptual Test Plan - A test plan has been proposed for the evaluation of a recycling domestic wastewater system, which employs conventional biological primary and secondary treatment, and an advanced physico-chemical tertiary system to produce potable water. At predetermined intervals, samples will be taken for chemical, physical, and biological analyses. Initially the samples will be taken at the beginning and termination of each step in the recycling system. After baseline data has been established, periodic samples at special points will be analyzed to determine specific characteristics and gather performance and reliability data on the total recycling system.

The objective of this effort is to develop pilot plant performance data on a domestic wastewater to potable (as defined in Table I) water recycling system in order to better understand the idiosyncracies of such a system, and to provide data for the development of a degree of confidence and reliability of the system. These data are a prime requirement prior to the approval by any authority for the installation of such a system for domestic use. The data will also serve to confirm the Appendix A Computer Program output.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) is investigating the reclamation of potable water from a domestic wastewater source. The time period for the development of such a system was established as being in the mid-1970's. Such a requirement is becoming a necessity in view of the fact that new sources of water are becoming increasingly difficult to find. In the case of the western part of the United States these sources may also be remotely located. Thus, impoundment costs, piping, tunneling, and pumping costs are increasing at a rapid rate. Furthermore, bond issues for future water development are becoming more difficult to sell to the voting public. As an example of this, Denver recently voted negatively on a proposal to fund a multimillion dollar water development plan which would assure an adequate water supply through the year 2000. The Denver Water Board is seriously studying total recycle implementation by 1985 for industrial and domestic usage as the alternative solution. Similar instances can be cited for the high population density areas of the East where substantial percentages of the water intake to water treatment facilities are made up of effluent from wastewater treatment plants.

It is estimated that the cost of treating water to the potable level will exceed the cost of tertiary levels, required by EPA in 1977, by approximately 20 to 30%. Therefore, in water short areas no additional costs would be incurred in the use of directly recycled water.

Another consideration is the post 1980 "zero discharge" legislation recently enacted by Congress. This law will make necessary a tertiary treatment system which will provide for a wastewater treatment plant effluent which will be purer than most of the current potable water sources. Carrying this logic one step further, leads to the reasonable conclusion that "zero discharge" quality water will serve as controlled indirect reuse where sources are abundant and as a direct source of reuse water in regions of sparse supply.

The study effort was directed at the formulation of a conceptual design of a water management system capable of producing a safe supply of potable water with domestic wastewater as its source. As technology background for this purpose, advanced wastewater treatment processes for both Aerospace and Municipal applications were studied.

CONCEPTUAL DESIGN

This Section describes the conceptual design of a wastewater recycling system for producing potable water and suitable for continuous recycling. Details on the evolution of this concept are presented in the Final Report identified as MCR-72-277 and dated January 1973.

A. REQUIREMENTS

The requirements to be met by the water recycling system were as follows:

1. The system shall be capable of providing water management for a 500 unit dwelling complex of 2000 people.
2. Daily per capita sewage generation shall be 100 gallons or 200,000 gal/day total system flow. This value includes infiltration allowances and safety factor.
3. The system shall provide for steady state flow through the unit processes.
4. Sewage composition shall be as defined in Table 1.
5. U.S. Public Health Service Drinking Water Standards, Table 2, shall be used as purity criteria for the production of potable water.
6. The system must be available for prototype testing in the mid-1970 period. Therefore, no new major development of unit processes would be compatible with the schedule.
7. The design shall meet national plumbing, electrical, and pressure vessel codes.
8. Peak supply requirements and disposal requirements may be obtained from municipal services.

B. SELECTED APPROACH

In order to formulate a conceptual design of a water management system for a group of 500 dwellings utilizing the recycling of wastewater concept, it is necessary to examine a large number of unit treatment processes for the wastewater. These processes range from "Grit Removal" at the input to the wastewater treatment plant to the final process of "Sludge Disposal". The review and integration of these unit processes led to the definition of the preliminary design of the system.

A study of the available hardware has shown that in the size range of 200,000 gallon per day wastewater flow, the first portion of the treatment system can be accommodated by existing "off-the-shelf" hardware. This means that the most cost effective approach to Primary/Secondary treatment lies in the utilization of such equipment, Figure 1. The tertiary unit processes must, of course, be appended to the Primary/Secondary elements in order to achieve potable water. These unit processes are shown in schematic form in Figure 2. Unfortunately these are not "off-the-shelf" units and must therefore be designed and integrated into a composite system.

C. DESIGN AND INTEGRATION OF UNIT PROCESSES

1.0 Packaged Primary and Secondary Sewage Treatment

The use of packaged systems for primary and secondary sewage treatment offers several advantages. Many of the systems available have been operating successfully for years. These units reflect the latest technology in biological sewage treatment, yielding the highest quality effluent possible. Package units are mass constructed which greatly reduce design and building costs. These units are designed to optimize space.

The manufacturers of package sewage treatment units were contacted. Technical and cost data were collected and evaluated.

The evaluation of available package primary/secondary sewage treatment systems shows that a completely-mixed activated sludge treatment (Fig. 1), yields the highest quality product water with the lowest operating and equipment amortization costs per 1000 gallons of water treated.

Table 3 gives a summary of that evaluation. The quoted cost values are based on an amortization period of 20 years equipment life and a rate of interest of 4%. It should be noted that these costs include installation of the equipment.

1.1 Selected Tertiary Processes

Following good primary and secondary treatment, the flow stream will enter the tertiary section of the plant which begins with a holding or surge tank. Flow from this tank will be evenly distributed throughout the day to the downstream processes and thus ironing out hydraulic overloads. The tank will also handle shock loads of water from filter backwashing and the chemical thickener overflow. Unit processes are listed below in their order of flow.

1.2 Chemical Precipitation

The first downstream process will be chemical precipitation. Lime in the hydrated form, $Ca(OH)_2$ is the chosen coagulant because of its effectiveness in phosphorus, suspended solids, bacteria, and trace metal removal. Based on 200,000 gpd the lime requirements will be 350 to 700 lbs/day. The actual dosage is a function of the local waste water quality. Rapid mixing for 30 seconds is followed by 5 minutes flocculation; then clarification.

1.3 Recarbonation

As a result of using lime, pH reduction is necessary. This will be accomplished by bubbling CO_2 into a recarbonation tank to a pH of 9.3.

More chemical sludge ($CaCO_3$ and residual phosphorus) will be generated in the accompanying clarifier (100 gpd). Additional CO_2 injection lowers the pH to a near neutral 7-8 and the flow stream enters another holding tank.

1.4 Filtration

This tank is used for feeding the four multimedia filters. Two filters are operating simultaneously (5 gpm/ft^2) with two units on standby. When head loss reaches 15 ft or measured turbidities are high (greater than 4 units) the filter is automatically backwashed (15 gpm/ft^2) as one of the standby units becomes operable. Backwashing will be necessary on the order of every 24 hours. This will result in approximately 3000 gal. of backwash water which is pumped to the first surge tank. Filtration is an essential part of the phosphorus removal processes as well as to remove suspended particles which inhibit disinfection. Aerobic conditions are maintained in the filter by frequent backwashing and chlorinating the backwash water continually sterilizes the media.

3

Following filtration the already highly treated wastewater is passed to the more sophisticated parts of tertiary treatment.

1.5 Nitrogen Removal

Effective nitrogen removal is accomplished by selective ion-exchangers. The beds are similar to the preceding filters in shape and will operate at 8 gpm/ft^2 gravity flow until the exchanging potential is exhausted.

Regeneration (every 12 hrs) will be on a time basis with a known number of bed volumes passing through the columns.

Four columns are required in the process; the first two operating in series and the remaining two in a standby mode. The lead column receiving the highest load will be exhausted first. The regeneration cycle begins and the second column becomes the lead while the third or standby unit acts as a polishing process. Upon regeneration completion, the first column becomes a standby unit awaiting its turn in the progression. The fourth column is in a permanent standby mode and will be used only upon mechanical failure of any of the preceding three.

Regeneration not only restores the exchanging capacity of the resin but cleans the filter as well. Ten bed volumes of regenerating liquid ($NaCl$ and $CaCl_2$) are passed up flow through the columns in 2 1/2 hours. This will dislodge any entrapped material and remove the ammonium ions. The flow passes into a holding tank where electrolysis converts the chlorides present to hypochlorite which oxidizes the ammonium ions to nitrogen gas which escapes to the atmosphere and permits reuse of the regenerant stream. Thus, no liquid or solid by-products are generated in the entire process. Power consumption is expected to be in the range of 400 kw-hr/day.

The remaining trace amounts of nitrogen compounds will be completely removed by the addition of a heavy chlorine dose to the flow stream.

1.6 Carbon Adsorption

The downstream carbon adsorption step will remove any chlorinated hydrocarbons and free chlorine residuals formed in the previous step.

Activated carbon columns, again similar in design to the filter and exchangers, will be used to remove refractory organic compounds

which have passed through the preceding processes. Five columns, 2 operating in parallel in the upflow mode and the other 3 on standby will accomplish this important task. Upflow operation will eliminate the need for backwashing and ensures complete saturation of the carbon prior to discharge. Rates of 6 gpm/ft^2 and a detention time of 30 min. will give column life expectancies of up to 6 months. Regeneration is possible through high temperature furnaces but it is more practical in a smaller plant just to replace the carbon with fresh material.

1.7 Reverse Osmosis

Inorganic salt removal will be accomplished by reverse osmosis units. Excellent reduction in pathogens and residual metals is anticipated. Flushing of the membranes can be provided for prolonged life but tube replacement is expected upon exhaustion.

1.8 Disinfection

Chemical quality is a very important factor in the renovation and recycling of wastewaters but disinfection is the key word for potable reuse. For this purpose two separate sterilizing processes are included.

Ozonation (5 mg/l) by itself will destroy any pathogenic bacteria still remaining but chlorine (.5-1 mg/l) is added to produce a residual sterilizing effect.

All of the processes stress reliability and consistency in performance. Safety, flexibility and ease of maintenance will be designed into the units. Proper care, however, by trained personnel is a requirement for a smooth operating plant.

1.9 Solids Handling

The amount of chemical and biological sludges produced daily is a function of several variable including flow, chemical dose, magnesium and phosphorus, suspended solids, and biological growths.

Some promising results have come from numerous research situations involved in the efficient disposal of waste sludges. The most common unit processes include thickening, centrifuging, and incineration. Chemical and biological sludges are treated as separate entities while

the numerous overflows and supernatants are mixed throughout the system.

For the small plant (200,000 gpd) considered in a total reuse program, solids handling will be of major importance. Optimum water recovery from waste sludges will be necessary to insure limited wasting.

1.10 Bulk Solids

Raw wastewater enters a flow measuring device (Parshall flume or calibrated floating gage) then onto a selfcleaning bar screen where large materials as rags and sticks are removed. The expected volume of screenings is 1-2 ft^3/day. Upon entering an aerated grit chamber grease and floatables are collected from the surface and grit scraped from the bottom. Volumes of grit will approach 1-2 ft^3/day and grease .5-1 ft^3/day.

1.11 Organic Solids

Primary clarification will produce top skimmings in a volume of .5-1 ft^3/day. All of these waste solids are to be collected and disposed of by normal landfill along with the final sludges.

From the preliminary treatment section wastewater is allowed to settle in a primary clarifier at a loading rate of 1000 gpd/ft^2. Primary sludge (300 gpd) is collected off the bottom at 5% solids. Waste activated sludge (400 gpd) at 2% solids is brought from the secondary processes and added to the clarifier where it is allowed to settle with the primary sludge. Polymer addition (.1-.5 mg/l) is necessary for improved clarification. The total sludge withdrawn from the primary system is therefore 700 gpd at a 3% solids level. More polymer is added (.1-.5 mg/l) and the sludge is gravity thickened to 6%. 350 gpd of thickener overflow returns to the head of the primary system. Thickener underflow (350 gpd at 6%) is pumped to a centrifuge where a heavy dose of polymer (2 lbs/day) is added. Centrifugation dewaters the organic solids to 40% and a flow stream of 50 gpd. Centrate of 300 gpd is also returned to the primary clarifier.

Dewatered chemical sludge is added and both streams are stored for disposal to land fill. Seventy-two (72) gallons of water/day are lost from the system in this manner.

1.12 Chemical Solids

Chemical sludge is formed from the addition of lime to the primary effluent. It is allowed to settle in a chemical clarifier at a loading rate of 1000 gpd/ft^2. Approximately 5000 gpd of 1% chemical sludge is drawn off the bottom of the clarifier. Loading a gravity chemical thickener at 1000 gpd/ft^2 results in a concentrated chemical sludge of 600 gpd at 10% solids. An additional 1000 gpd of chemical sludge is added to the thickener from the first stage recarbonation settler. Thickener underflow (600 gpd) is pumped to a centrifuge where heavy polymer doses (1 lb/day) dewater the sludge to 50 gpd at approximately 80% solids. The dewatered chemical sludge is combined with the dewatered organic sludge and bulk solids which are disposed of by landfill.

1.13 Miscellaneous Solid Waste Streams

Wastewater filters require backwashing daily. At a rate of 15 gpm/ft^2 and a 10 minute backwash period, the volume will approach 3000 gal/backwash. This volume will be added to the holding tank.

Demineralization of the wastewater will result in a concentrated brine solution from the reverse osmosis units. Satisfactory concentration and disposal of the brine can be accomplished by ponding (evaporation) and haulage to suitable landfill.

1.14 Cost

The design of the preliminary system will accommodate the removal of all pollutants which have been added during the "use" cycle. Hence it will meet the 1977 EPA removal requirements as well as the 1985 "Zero Discharge" EPA Criteria.

Recent presentations by EPA enforcement personnel at national meetings indicate that EPA does, indeed, plan to enforce the recently enacted Federal water pollution legislation. Such enforcement then provides for mandatory tertiary treatment and hence the achievement of potable water is only a matter of implementing the proper development plan to assure that the tertiary system effluent is free of pathogens.

Partial recycling of water may be considered as a means of cost saving. However, the amount of money saved is small and the system

complexity to achieve the savings may make such an approach undesirable. For example, the use of partially treated water for sprinkling and cooling towers/evaporative condensers poses the problem of water storage during cool (when not air conditioning or sprinkling) periods in the summer time, i.e. "matching" of cooling load/sprinkling load is an involved problem. Furthermore, partially treated water always contains the threat of pathogenic contamination and residual chemical buildup.

The actual savings by partial treatment are related to the deletion of the reverse osmosis unit process and amount to approximately 40¢/1000 gallon or 10¢/day/dwelling unit. Such savings would not appear to be warranted when weighed against the complexity of control of a "split" system i.e. one which uses partially treated water.

D. STUDY TASKS' SUMMARY

A summary of study tasks required to support the preliminary design of the wastewater recycling system is presented below. The outline follows the order of tasks as required by the Contract Statement of Work.

1.0 Water Consumption

The domestic water use profile, peak-load and hot water requirements, and nature of dissolved and suspended solids are discussed for the typical dwellings. An average family occupying a typical dwelling uses water for the purposes of drinking, food preparation, dishwashing, toilet use, bathing, laundering, garbage disposal, lawn watering (except in apartments), household cleaning, etc. It is assumed that a household shall have sufficient amounts of hot and cold water available on demand.

1.1 Dwelling Unit

The in-house water consumption rate for a single family dwelling depends mainly on the number of people occupying that residence whether it is a house, mobile home or apartment. The average single family dwelling requires additional water for lawn care. A mobile home uses less sprinkling water due to the reduction in lot area. Apartments require water for lawn care as well as swimming pools, steam rooms, etc.

1.2 Individual

It is proposed that the EPA value for daily per capita water consumption of 64 gallons be retained as design criteria. Furthermore, in view of excellent correlation with other data sources, it is recommended that the values of water usage, ascribed by EPA, to individual water usage functions, be retained.

1.3 Peak Loads

Hydrographs of water flow in residential areas throughout the country generally indicate two peak periods. One occuring in the morning (9:00 a.m. to 1:00 p.m.) when the laundry and housecleaning is

being done. The other occurs between 6:00 and 9:00 p.m. when meals are being prepared, showers used and lawns watered.

In order to arrive at the specific design criteria for the waste water recycling system the following factors should be considered:

(a) System operation will be optimized by continuous operation.

(b) A safety factor of 1.5 to 2.0 will be evaluated.

1.4 Hot Water Requirements

The American Society of Heating and Ventilating Engineers (ASHVE) has established an equation for the calculation of the hot water required by a home.

Hot water required = 0.66 x cold water used.

This formula is commonly used by consulting engineers in design of home hot water systems and has been in common usage for the past 35 years. The value of 29 gpcd hot water established by EPA Report should be changed to 42 gpcd hot water. It should be noted that this criteria is intended for use of hot water heating equipment/systems and is not directly related to the design of the wastewater treatment system.

1.5 Nature of Domestic Waste Water

Individual household waste water quality is in most respects similar to that encountered in domestic waste water treatment plants handling limited industrial discharges. The home today is a veritable chemical depository and the qualities mentioned above must be considered.

Wastes from houses, mobile homes, and apartments are mixed within the municipal sewage system to produce relatively constant per capita amounts of suspended solids and organic matter in terms of COD and BOD.

Human body wastes (feces and urine) are excreted in quantities varying with age, sex and nutrition. Fecal matter contains food residues, the remains of bile and intestinal secretions, cellular substances from the alimentary tract and bacterial cell masses in large amounts (about a quarter of the weight of feces). Bulky foods usually contain much cellulose and undigestible materials derived from roughage. The feces of reasonably well-fed people average about 90g per capita daily, or

20.5 g on a dry-weight basis and range from about 25 g for females to 150 g for men. Urine is excreted in amounts of about 1200 g per capita daily ranging from 500 g for females to 1500 g for men.

Fresh household sewage has a slightly soapy or oily odor and in appearance is cloudy, somewhat like grey dirty washwater. It is normally alkaline when fresh but tends to acidify as it becomes stale in 2-8 hours.

Household waste water may differ from domestic sewage only in respect to particle size and large unground substances. It is well to keep in mind that wastewater is essentially 99.97% pure water and only 0.03% additional materials.

2.0 Consumer Appliances for Low Water Consumption

After reviewing the data gathered from the different manufacturers of plumbing fixtures, and major appliances, it becomes quite apparent that even though the manufacturers of these devices are cognizant of water problems and wastewater flow, no significant development which impacts this problem has come out since the 1968 EPA report. This is primarily due to the lack of public interest for such devices, the added costs incurred in the Research and Development of such devices, and the lack of public awareness concerning water shortage.

It should be noted, however, that a reduction of daily water flow reflects itself largely in the recycling system pumping power consumption. The cost of extending the side walls and bottom of concrete tankage is small compared to the overall cost of the system. Also, most unit process equipment costs involve mechanical equipment and controls rather than tankage. Chemical costs for processing remain the same in view of the total load of pollutants remaining the same. Furthermore, Carbon Column and Clinoptilolite bed sizes are not reduced.

The savings are small even when conservative allowances are made for system size reduction; the daily cost saving per family of (4) would be 8.4¢. When weighed against the cost of special water savings devices and the problem associated with reorientation of the public, it would appear that there is little to be gained in the use of water savings devices when used in connection with a waste water recycling system.

3.0 Water Quality Monitoring

In order to achieve safe recycling of domestic wastewater for potable application, it will be necessary to provide the capability of monitoring the following parameters:

(a) Biological quality

(b) Total dissolved solids

(c) pH

(d) Suspended material

(e) Organic content

(f) Oxygen demanding substances

(g) Inorganic ions

It is proposed that with close control of these seven areas that a sufficient number of quality parameters will be included to insure a potable water.

During the developmental stages of the prototype water recovery system, of course, all of the significant parameters shall be monitored in accordance with the latest edition of "Standard Methods for the Examination of Water and Waste Water". The reclaimed water will use AWWA goals and as a minimum meet latest USPHS recommended standards. This additional laboratory work will provide a history of reliability data to verify a successful operation with a limited number of in-line monitors.

4.0 Baseline Concept

4.1 Guidelines for the Baseline Concept

The following guidelines will be used for the establishment of the baseline concept:

1. The baseline concept is to require little or no additional effort on the part of the user from the use of conventional systems currently being installed in single family dwellings.
2. The baseline concept is to interface with a conventional municipal type water supply and sewer system.

4.2 Configuration

The baseline concept will meet the requirements as defined for a single family dwelling:

Single family house with one and a half baths; having a shower and tub combination in the full bath. A shower in the half bath, and a toilet and wash basin in each bathroom. The dwelling has an automatic dishwasher, kitchen sink, garbage disposal unit, and provisions for a clothes washer.

Consultation with leading personnel in the plumbing and major appliances manufacturing industry led to the following conclusions for the baseline concept:

1. Aerator faucets are now standard equipment in bathroom lavatories and kitchen sinks in newly constructed homes (post 1970). This device has an average water savings of two gallons per day for a family of four. The cost of the device is under $0.50 per faucet with not more than four aerators per dwelling.
2. American Standard, one of the leading manufacturers of plumbing fixtures in the United States, has on the market a water saving toilet, which cuts the amount of water used, per flush, by one third. It is accomplished by a shallow trap and smaller water tank. This type of toilet is being installed in a large number of newly built homes due to the refined low profile styling, and larger color selection. The toilet has an average water savings of 30 gallons per day for a family of four, each flushing five times.

It becomes apparent upon evaluation of the water and sewage handling hardware in a newly built home, that an attempt is made to utilize those devices which are econom ical but above all, attractive to the homeowner, e.g. low profile toilets. Correspondingly, these units happen to be the primary water savers in use today.

The baseline concept, based on the above considerations, is, therefore, defined as containing the plumbing fixtures and provisions outlined for the single family house. Use will be made of the water saving low profile toilet and aerator faucets. The net result of this approach is three-fold:

(a) Assured public acceptance.

(b) A 12.5% water savings.

(c) A system which meets existing codes.

4.3 Background

Other plumbing or major appliance devices which save water were evaluated and not considered suitable for application to the baseline concept. See Final Report MCR 72-277 for a detailed discussion.

4.4 Cost Analysis

To arrive at water and sewage cost to the single family dwelling for the baseline system requires analysis of the following areas:

1. Current and projected initial cost of the baseline concept.
2. Growth trends in water and sewage requirements.
3. Current and projected cost of water supply and waste water collection.
4. Current and projected cost of water distribution and sewer mains.
5. Current and projected cost of waste water processing.
6. Current and projected direct water and sewage costs to the user.

4.4.1 Current and Projected Initial Cost of the Baseline Concept

The plumbing costs of a new project home similar to that established as an "average single family house", section 8.4.2, would be about $1450. This home would be supplied with copper piping for water supply and plastic pipe for waste water. The connections to the water main and to the sewer are not included.

It is estimated that the plumbing costs have increased 16 percent over the ten year period from 1961 to 1971; while during the last year costs are 8 percent higher. In view of a much sharper rise due to substantial labor cost increases, and no new material cost reductions on the horizon, no further cost extrapolation is reasonable at this time.

4.4.2 Growth Trends in Water and Sewage Requirements

As the population of a given city increases so, naturally, will its total water requirement and use (water and sewage). These trends are an important factor in the projection of water costs; since as the city grows, water requirements are met by previously untapped distant sources or treatment of local waters of lesser quality. Each causes an overall increase in costs. Many cities with water shortages have had to turn away large industries due to the lack of available water.

The gallons per capita usage including industrial requirements steadily increases even though the annual increase is only 1 gpcd per year. However, domestic per capita usage is not projected to increase in the next 40 years. Therefore, per capita domestic sewage flows also would not increase.

4.4.3 Current and Projected Cost of Water Supply and Waste Water Collection

A cross section of costs for water and sewage treatment in the United States reveals a charge of 46¢/1000 gallon of water and 36¢/1000 gallon of sewage.

Water costs to the user are based upon the initial capital outlay for the street mains, maintenance, and the operating costs of delivering water to the household. Sewage charges include similar elements noted for water.

Analysis of Cost Data from the various Water Boards indicates the expected rise in the cost of water to the homeowners will amount to approximately 0.9% a year for the balance of the century.

This is due in part to a system development charge of approximately $600 for every new house. This cost is above that of the street lateral and house connection incurred in the original dwelling price. Water Board economists have proposed a more realistic tap fee of a flat $2,200 to come on the system as this is the actual cost to the Board. The proposed fee includes water resources costs, dams, trans-mountain diversions, pipelines, canals, storage reservoirs, channelization, stream diversions, terminal reservoirs, treatment plant amortization, pumping, and distribution system capital costs. Monthly water bills would cover operating and maintenance expenses. Data from the various Department of Public Works indicates a 1.3% annual increase for Sewage Service.

Waste water collection systems, sewer trunks and mains are usually funded by improvement bonds or federal grants and paid off with sewage treatment rates or direct taxation. Costs are expected to increase approximately 1% a year.

4.4.4 Current and Projected Cost of Water Distribution and Sewage Main and Trunk (subdivision)

With respect to water distribution, capital outlays to the homeowners include the street laterals, usually $10 a front foot for an 8-inch pipe and the house connection as installed by the contractor, commonly $500-600 including meters. These combined costs are reflected in the original dwelling price and totally run from $1000-1400 per unit in a new subdivision.

Sewer laterals average $15 a foot for installation with the house connection costing in the range of $200-300. Thus, the costs for sewer connection in a new subdivision is estimated to be approximately the same as the water service.

Contacts with several home builders in the East, Midwest and Western Regions of the country verify the foregoing figures. Projected costs for such water and sewer lines are expected to increase at a 3.2% rate.

4.4.5 Current and Projected Cost of Waste Water Processing

The primary purpose of sewage treatment is to separate liquids from solids, treat each to an innoxious state and dispose of in an efficient desirable manner. This is accomplished by some or all of the following processes:

	Common Cost/1000 Gal
Primary Treatment	$.03-.10
Grit chambers	
Sedimentation basins	
Screens	
Grinders	
Grease removers	
Pumping	
Secondary Treatment	$.10-.15
Activated sludge units	
Extended aeration and modifications	
Trickling filters	
Lagoons and ponds	
Tertiary Treatment	$.10-1.00
Carbon adsorption	
Phosphorus and nitrogen removal processes	
Demineralization steps	
Sterilization	
Filtration	
Solids Handling	$.10-.20
Digesters	
Vacuum filters	
Centrifuges	
Dryers	
Incinerators	
Land fill	

These costs reflect the capital, amortization, operation and maintenance charges, and are heavily influenced by system's location as well as capacity.

Future costs of waste treatment will be a function of the population, area served, land acquisition, quality of product water, and construction and operating parameters - building materials, electricity, gas, etc.

In essence, as water quality or effluent standards increase, newer and better processes will be needed to accomplish the goal. This growth and improvement cost will eventually reach the public at large.

Sharp increases are expected within the next 10 years as reflected by public concern for pollution free waters. Federal legislation has now been approved for 98% removal of pollution by 1977 and 100% removal by 1980.

As a general indicator of this increase due to higher standards the following example is given.

1. Present sewage treatment costs run from $.15-.30/1000 gal for a well operated secondary plant.
2. Lake Tahoe's tertiary plant produces water at a cost of $.60/1000 gal including a sophisticated disposal method.

Therefore, it is indicated that sewage treatment costs can easily double within the next decade as the country as a whole is brought toward a tertiary requirement.

4.4.6 Current and Projected Total Water and Sewage Costs to the User

From the information gathered in the previous sections it appears the single family dwelling can realistically anticipate the following costs for water and sewage service as typified by the Denver area.

Water

$2200	System Fee
$1200	Physical Connection
$3400	Total Charge

The yearly water bill averages $85. This and the physical connection cost is expected to rise at 0.9% and 3.2% respectively a year over the coming years.

Sewage

$1200	Physical Connection
$ 100	Proposed Tapping Charge
$1300	Total Charge

Yearly sewer bills average $50. This and the physical connection cost is expected to rise at 1.3% and 3.2% respectively a year over the coming years.

It must be kept in mind the actual fees presented are not incurred by the homeowner at one time but instead paid back to the funding agency over a period of years through rates and taxation.

Costs are offset somewhat by federal grants but the monies involved here eventually reaches the public's pocketbook.

5.0 Applicable Aerospace Technology Concepts and Hardware

There have been many processes or techniques devised to accomplish the tasks of water recovery and waste management for aerospace application. However, few of these have ever reached the prototype stage and even fewer have resulted in qualified systems. It is significant to note that aerospace potability standards are much less stringent for this application than for domestic application which must meet the test of a lifetime application.

5.1 Water Recovery Systems

Man requires more pounds of water each day than oxygen or concentrated food. Consequently, research and development of processes for recovering potable water from urine was begun in 1958. Development of these processes did not proceed as fast as originally anticipated because hydrogen-oxygen fuel cells were developed for auxiliary power, and they produce more water than required for ingestion. Since fuel cells have a lower weight penalty than solar cells on manned missions up to two months duration, water recovery systems will probably never be used on shorter missions.

Humidity condensate is relatively good water because it has experienced a change-of-phase before it is collected. Consequently, particulate and adsorption filtration are usually sufficient to meet potability standards. However, gross contamination is highly probable in a weightless state so another process should be available to back-up the filtration system. In either case, post sterilization must be provided because most condensate contains enough nutrient to support biological activity.

A relatively large number of processes have been devised and/or evaluated for recovering potable water from urine. The vacuum distillation and air evaporation techniques have been most successful because they provide a phase change at temperatures low enough to avoid the formation of large quantities of ammonia, which is easily absorbed by condensate. In either case, pretreatment chemicals and post-treatment filtration and sterilization are required to meet potability standards.

Wash water can be renovated by membrane and/or absorption filtration.

After ten years of research and development work, it is not possible to state which technique will be most effective on future missions. The air evaporation process is inherently the most reliable process; however, all of the latent heat must be available at a low weight penalty, and it must be removed from the condenser. A compression distillation unit is more complex - but it reuses latent heat and therefore is less dependent upon other subsystems.

5.2 Waste Management Systems

The collection, treatment and disposal of wastes on board manned spacecraft has proven to be a difficult and often neglected task. The Project Mercury and Gemini astronauts used a plastic bag to collect urine for post-flight analysis; because of the short mission durations, the Mercury astronauts did not require equipment for collecting feces. The Project Gemini spacecraft originally was to include a pneumatic collector in each seat; however, this was abandoned in favor of a manual bag when it was determined that the seats (ejection) could not accommodate a fecal collector. The Project Apollo Command Module was also supposed to have a relatively sophisticated pneumatic collection system for urine, feces and cabin debris; this system was finally abandoned in favor of manual collection bags when contamination problems were encountered. All of these waste management systems have been criticized by the astronauts, and obviously are unacceptable for longer duration missions.

Eventually, spacecraft will contain a system for disposing all solid wastes, because the storage volume will be impractical. A pyrolysis/incineration unit, or a biological digester will probably be developed for this purpose. Another alternative is to use the waste as propellant in a thruster, which is required on spacecraft for attitude control and

velocity corrections. Obviously, a great deal of development and qualification remains to be accomplished.

6.0 Integrated System Design

In order to formulate a conceptual design of a water management system for a single unit dwelling or group of dwellings utilizing the Baseline Concept, it is necessary to examine a large number of unit treatment processes for the wastewater. These processes range from "Grit Removal" at the input to the wastewater treatment plant to the final process of "Sludge Disposal".

6.1 Primary and Secondary Treatment

In conventional and most activated sludge systems, the raw wastes are mixed with return sludge at one end of the aeration basin. The microorganisms in the mixture are thus subject to the full impact of any shock load. Their response is nearly instantaneous and unvarying; the results are high growth rates and very large oxygen demands. If air is adequate and the tank large enough the waste is stabilized before it leaves the tank. The net effect is one of a constantly changing microbial population. Consequently, equilibrium conditions are not established and operation is difficult. Insufficient air can result in filamentous growth with subsequent clogging and sludge bulking. Many modifications have been attempted to create optimum conditions. But the most significant contribution to technology has been the recent application of a knowledge of biochemistry to the activated sludge process. This awareness of acute relationships has enabled the development of the complete mix flow pattern.

Even loading distribution throughout the entire basin allows a predictable organism response, a uniform growth and oxygen demand. Shock loads are buffered and equilibrium conditions are established. This results in a stable and uniform operation.

The complete mix system best meets the optimum conditions now known to be desirable and necessary for a stable, predictable biological system.

Good primary and secondary treatment will in effect remove 80-90% of the BOD, greater than 50% of the COD and 90% of the suspended solids. The effluent, however, will contain considerable contaminants in the form of oxygen demanding substances, bacteria, trace elements, dissolved organics and inorganics and nutrients.

6.2 Tertiary Treatment

Modern technology has resulted in a number of advanced wastewater treatment processes which have the capabilility of converting secondary effluent to a potable grade product for any use in the community. Although sophisticated in nature the various processes have proven reliable and efficient in a number of pilot and full scale operations.

Much work has been done recently to evaluate the feasibility of applying physical-chemical treatment techniques such as chemical coagulation, filtration, carbon adsorption and demineralization directly to raw sewage or primary effluent to eliminate entirely the need for biological processes. This approach offers several advantages over biological treatment: (1) space requirements are reduced by a factor of about four, (2) susceptibility to upset due to biologically toxic materials is eliminated, (3) the processes are more adaptable to rapid variations in influent quality, (4) heavy metal concentrations may be reduced greatly, (5) nondegradable organics are removed to a greater degree, and (6) the processes are more amenable to fail-safe approaches than biological processes alone. However, in regard to the last point, biological processes in series with physical chemical processes offer even greater reliability, in that redundancy for organic removal is then provided.

Reservations are present, however, in strictly physical-chemical treatment (PCT) due to the fact that there are not yet any operating full-scale plants from which to estimate capital and operating costs, long-term operating problems and consistency of effluent quality. For example, the control of Hydrogen Sulfide generated in columns of granular carbon due to the high applied soluble BOD is a major operating problem for which an inexpensive reliable solution has not yet been demonstrated. At this time, the general role of purely PCT approaches appears to be that of providing a solution in those cases requiring slightly better removals of BOD and COD than that normally provided by biological treatment. They are also applicable in cases where the presence of biologically toxic materials or space limitations prevent the use of biological processes. However, it is better suited to cases where the goal is reduction of the total pollution load on a receiving water than those cases where it is desired to provide the maximum possible reduction of

organic compounds prior to recycling for reuse in a relatively confined environment. There is ample evidence that biological processes in series with PCT will provide a higher quality effluent.

6.3 Solids Treatment and Disposal

Many sludge treatment and disposal methods have been developed in the last few years with considerable success. However, no single process or series of unit processes will be optimum or useful in every situation. Most advanced waste treatment plants will produce chemical sludges which are different in nature than biological masses and may or may not be more difficult to handle. Mixing is sometimes a disadvantage because the combined sludge is more difficult to dewater.

Because there are many unknowns affecting dewatering of chemical-biological sludge mixtures, it is a wise precaution to investigate thoroughly the dewatering characteristics of sludge mixtures from the treatment of a particular wastewater prior to final selection of a full scale plant. The complexity warrants a pilot plant scale for lab technology does not adequately duplicate plant conditions.

For the small plant considered in a total reuse program solids handling will be of major importance. Which processes will find the widest use must be determined by further pilot plant evaluation.

RECOMMENDATIONS

Recommendations for implementing follow-on effort related to an overall development program for recycling of wastewater are as follows:

1. Development of a pilot plant test program to demonstrate the performance of a complete wastewater recycling system for generating potable water. The objective of such an effort would be to develop pilot plant performance data in order to better understand the characteristics of such a system, and to provide data for the development of a high degree of confidence and reliability of the system. These data are a prime requirement prior to the approval by any authority for the installation of such a system for domestic use. Furthermore, such data are the basis for design of a full scale operational prototype system.

   The pilot plant program would be approached in a two phase program:

   a) Phase I - Detail Specifications, Design, and Test Program Definition.

   b) Phase II - Fabrication, Assembly and Test.

2. As an alternate to the above recommendation, it may be worthy of consideration to integrate the potable water test program with either an existing tertiary pilot plant operation or a portion of the effluent from an existing full scale tertiary treatment plant.

   The first phase of such a program would consist of a survey of existing tertiary treatment pilot plant operations as well as full scale tertiary operations. This phase would include a study of how such facilities might best be employed to implement the potable water program. Design of unit processes and a test program definition would also be accomplished.

Phase II of the program is proposed as a fabrication, assembly, and test program to generate data as in (1) above.

3. Conduct a study of national as well as international water short areas that would be logical users of recycled wastewater for potable water supply. This study would include water quantity requirements and evaluate the economics associated with such reuse in the given areas.

4. Conduct a study of the long term impact of utilizing partially treated water for irrigation and cooling purposes. The study would include cost trade-offs between completely treated "zero discharge" water and partially treated water in various areas. It would also treat the problems associated with pollutant build-up and "run off" in soils and cooling equipment fouling.

5. Conduct a study of the thermal balance within a central utility system which provides electric power, heat, air conditioning, etc. to a community or building complex. The study would be conducted with a view toward evaluating the means that might be employed in utilizing partially treated water for sprinkling and cooling within the air conditioning system (cooling tower). Such usage is unfortunately subject to varying duty cycles from day to night and warm to cold weather, as well as the obvious seasonal changes. Means of water management for such a system would be included.

6. Laboratory studies of specific pollutants such as hormone concentrations in recycled wastewater and their possible build-up need to be conducted. Such studies can be bench-performed in the laboratory and would provide valuable data for the design of the prototype system.

Table 1 Water and Sewage Characteristics

Constituent (mg/l)	Supply Water	Raw Sewage	Use Increment
Organic Constituents			
BOD_5	0.0	250	250
COD	0.0	375	375
LAS	0.0	5	5
Grease	0.0	85	85
Nutrients			
Phosphate as P	0.04	10	10
Nitrate - N	0.03	0.6	0.57
Ammonia - N	0.03	20	20
TKN (Total Kjeldahl Nitrogen)	0.1	50	50
Organic - N	0.0	16	16
Toxic Chemicals:			
Lead	.03	.10	.07
Flouride	.91	1.1	.20
Chromium	.039	.05	.01
Arsenic	.001	.003	.002
Cadmium	.001	.001	--
Cyanide	.01	.01	--
Selenium	.001	.001	--
Barium	.085	.19	.11
Silver	.001	.008	.007
Copper	.04	.07	.03
Nickel	.015	.12	.1
Nitrate - N	0.03	0.6	0.57
Inorganic Ions:			
Chlorides	25	125	100
Sulfates	40	170	130
Sodium	25	150	125

Table 1. Water and Sewage Characteristics (Cont'd)

Constituent (mg/l)	Supply Water	Raw Sewage	Increment
Physical			
Alkalinity	90	250	160
pH	7.5	7.2	--
Hardness	80	200	120
Suspended solids	0.0	300	300
Turbidity (JTU)	0.7	250	250
Total solids	125	1000	875
Total dissolved solids	124	420	296
Volatile suspended solids	0.0	250	250
Microbiological			
Coliforms (#/100 ml)	0.0	10×10^6	10×10^6
Fecal coliforms (#/100 ml)	0.0	1.5×10^6	1.5×10^6
Fecal strep (#/100 ml)	0.0	1×10^6	1×10^6
Trace Elements			
Aluminum	.11	.16	.05
Bromine	.05	.19	.14
Cobalt	.001	.001	--
Columbium	.001	.001	--
Copper	.04	.07	.03
Germanium	.001	.001	--
Gold	.001	.001	--
Iron	.30	3.0	2.7
Lanthanum	.001	.001	--
Manganese	.04	.08	.04
Molybdenum	.08	.10	.02
Nickel	.015	.12	.1
Rubidium	.02	.06	.04
Strontium	.28	.40	.12
Tin	.001	.003	--
Titanium	.001	.1	.1
Tungsten	.001	.1	.1
Uranium	.015	.04	.03
Zinc	.13	.18	.05

Table 2. USPHS Drinking Water Standards

Substance	Recommended	Reject
Physical:		
Color (units)	15	----*
Odor (TON)	3	----
Turbidity (units)	5	----
Nonfilterable solids (mg/l)	----	----
SS (mg/l)	----	----
Microbiological (no./100 ml):		
Coliform	----	1
Toxic chemicals (mg/l):		
Arsenic	0.01	0.05
Barium	----	1.0
Cadmium	----	0.01
Chromium (+6)	----	0.05
Cyanide	0.01	0.02
Fluoride	1.3	2.6
Lead	----	0.05
Nitrate-N	10	----
Phenols	0.001	----
Selenium	----	0.01
Inorganic chemicals (mg/l):		
Aluminum	----	----
Ammonia	----	----
Calcium	----	----
Chloride	250	----
Copper	1	----
Hardness	----	----
Iron	0.3	----
Magnesium	----	----
Manganese	0.05	----
Silver	----	0.05
Sulfate	250	----
TDS	500	----
Zinc	5	----
Organic parameters (mg/l):		
CCE	0.2	----
CAE	----	----
MBAS	0.5	----
Oil and grease	----	----
COD	----	----
BOD	----	----

*---- Indicates no standard concentration established.

Table 3 - Package System Evaluation Summary Chart

No.	System	Pumping Horsepower Required	Cost/Cents 1000 Gal Operating	Cost/Cents 1000 Gal Capital Amort.	Total Cost/ 1000 Gal Cents	Capital Cost* (Dollars)	Technical/ Cost Rating
1	AWT	N/A	50	42	92.0	450,000	Excellent/13
2	Aquanox	N/A	33	34	67	350,000	Poor/12
3	Aquatair	12	1	13.3	14.3	165,000	Fair/7
4	Bio Disc Autotrol	1.2	1	9.8	10.8	100,000	Good/3
5	Case-Cotter	10	0.9	9.8	10.7	100,000	Excellent/2
6	Chem Pure	25	16	18.5	34.5	189,300	Poor/10
7	Chicago Pump	21.5	1.9	11.7	13.6	120,000	Excellent/6
8	Demco	80	14.2	21.5	35.6	220,000	Good/11
9	Dorr-Oliver	6.25	0.6	14.6	15.2	150,000	Fair/8
10	Dravo	40	3.6	11.7	15.3	120,000	Good/9
11	Lakeside Oxidation Ditch	20.5	1.8	9.8	11.6	100,000	Good/4
12	Lakeside Spirajet	31.75	2.9	9.8	12.7	100,000	Good/5
13	Marolf	45	4	5.7	9.7	62,000	Good/1
14	Permutit	42.5	4	10.3	14.3	104,000	Good/7

*(a) Preliminary Estimates; not to be construed as firm cost estimates.
(b) Includes installation cost

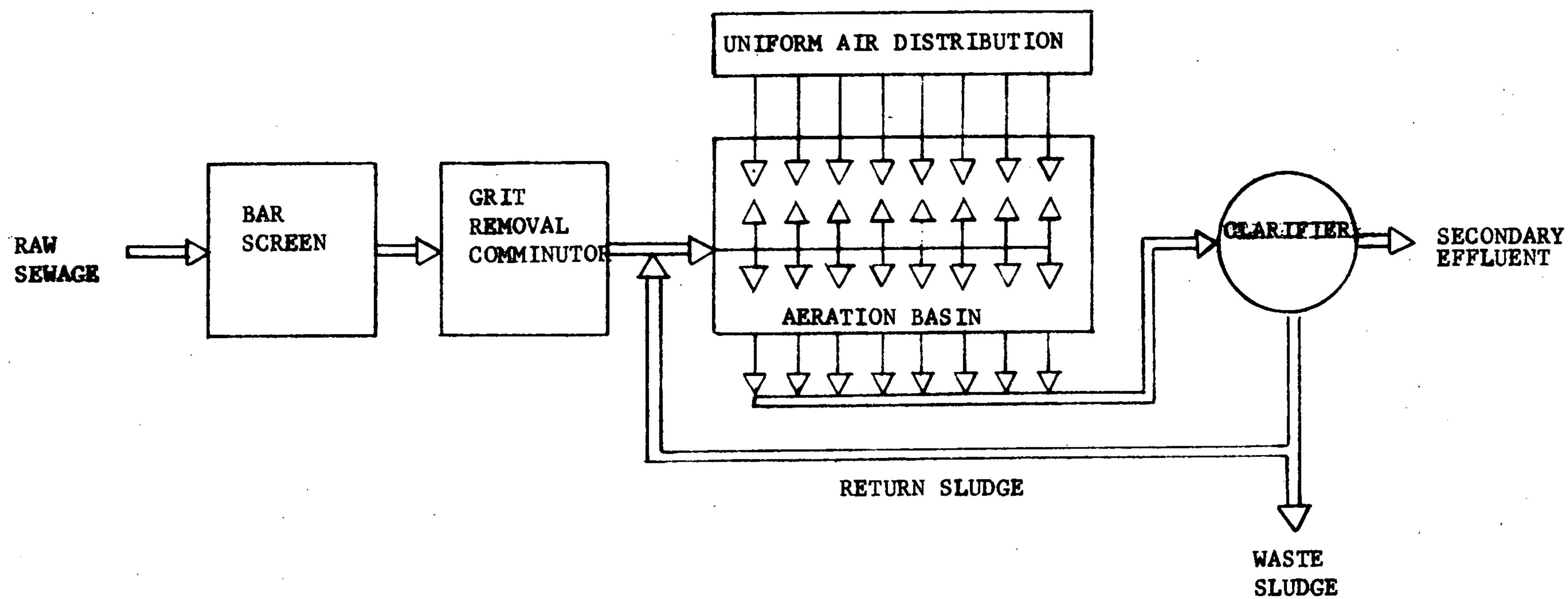

Figure 1 Schematic of the Completely Mixed Activated Sludge (Primary/Secondary) System

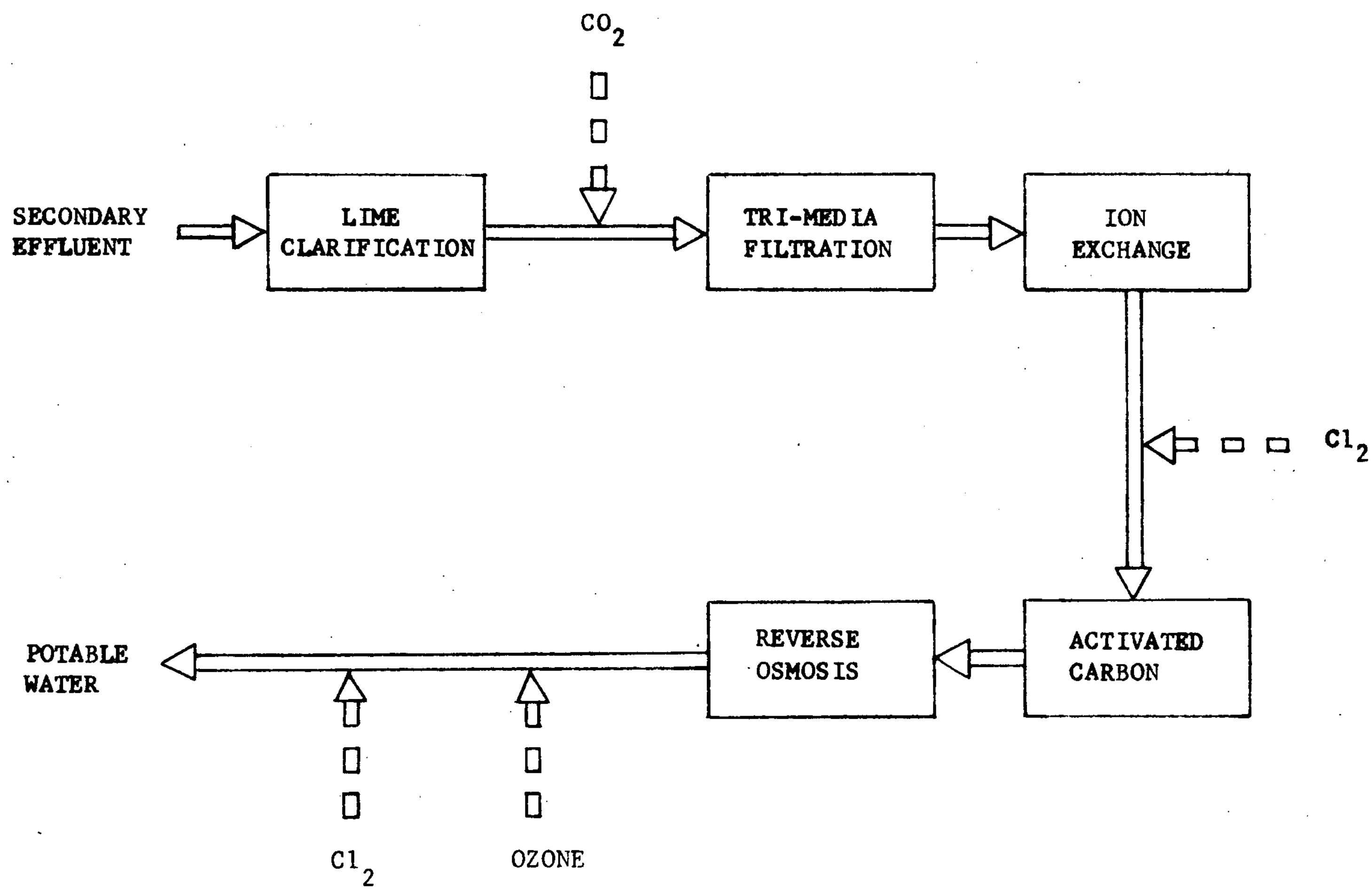

Figure 2 Recommended Tertiary System